7. Application of Mineral Magnetism in Atlantic Scotland Archaeology 2: Magnetic Susceptibility and Archaeobotanical Taphonomy in West Lewis, Scotland

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The use of two basic mineral magnetic measurements (mass specific magnetic susceptibility, χ, and frequency dependent susceptibility, k_{fd}) is described in the investigation of archaeobotanical taphonomy from nine sites in West Lewis. Magnetic enhancement was observed throughout a range of archaeological deposits on each of the sites sampled. It is proposed that this magnetic enhancement stems from the spread of ash from hearths or other burning activities. The link between magnetic enhancement, ash content and carbonised plant macrofossil concentration is demonstrated across the sites. Much of the carbonised plant remains recovered from archaeological sites in Britain were most likely carbonised in household fires and subsequently spread across the site by various dispersal mechanisms. This taphonomic model is confirmed for the nine sites investigated through the independent proxy of mineral magnetism. A key implication of the model in Atlantic Scotland is the very poor preservation environment for carbonisation of plant macrofossils in fires with peat as its main fuel.

INTRODUCTION

This paper describes the use of two basic mineral magnetic measurements (mass specific magnetic susceptibility, χ, and frequency dependent susceptibility, k_{fd}) to aid in the investigation of archaeobotanical taphonomy on nine sites in West Lewis, Scotland. It has long been acknowledged both within Atlantic Scotland (*cf.* Milles 1986; Bond 1994; Dockrill *et al.* 1994; Dickson 1994; Smith 1999) and Britain as a whole (Hillman 1981; Jones, G. 1984; Jones, M. 1985; 1996; van der Veen 1992) that much of the carbonised plant remains recovered from archaeological sites were most likely carbonised on household fires. A basic taphonomic model has been implicit and widely stated within this assumption is that involves three stages. (1) The pre-charring derivation of the plant material incorporated into the fires through direct or indirect human discard, (2) the process of charring and carbonisation within the hearth itself, and (3) the subsequent spread of ash from the hearth into the archaeological contexts sampled. It is the intention of this paper to test the validity of this model using the independent proxy of mineral magnetism on nine sites from Lewis, Scotland. The sites, ranging in date and function from a Bronze Age kerb cairn to Norse domestic structures, were sampled for both mineral magnetic analysis and carbonised plant macrofossils.

Heating as the primary mechanism for mineral magnetic enhancement on archaeological sites was first recognised by Le Borgne (1955; 1960), with the main processes of enhancement demonstrated by Tite and Mullins (1971) and Mullins (1977). Evidence of *in situ* burning can create the greatest concentration in a mineral magnetic profile across an archaeological site and a number of researchers have used this hypothesis to identify the likely position of a hearth (*cf.* Bellomo 1993; Morinaga *et al.* 1999) or structural conflagration (Krawiecki 1982). Identification of the spread of burnt material and ash using mineral magnetism, with general reference to site formation processes, has been demonstrated on sites comprising largely negative features (*cf.* McClean and Kean 1993) and more complex urban stratigraphy (*cf.* Boucher 1996). The first steps to distinguish and separate the mineral magnetic signatures resulting from anthropogenic or natural enhancement processes have been attempted for ash rich deposits on archaeological sites (*cf.* Crowther and Barker 1995; Marmet *et al.* 1999; Peters and Thompson 1999). This led to the recognition that different fuel types could produce slightly different mineral magnetic signatures (Peters *et al.*, this volume), a theme explored in more detail below.

Mineral magnetism has recently been used in Atlantic Scotland at Scatness, Shetland (Dockrill *et al.* 1995; Batt and Dockrill 1998) and St. Boniface, Orkney (Peters and Thompson 1999). Both exercises involved the use of mineral magnetism to assess source material and formation processes through sections of archaeological material in a soil test pit at Scatness (Nicholson and Dockrill 1998) and an eroding section of Iron Age and Norse occupation deposits at St. Boniface (Lowe 1999). The enhancement observed in archaeological layers at both sites stemmed from the input of ashy material into the various context types, with a magnetic enhancement factor of over 200 at St. Boniface. Unmixing of 85 hysteresis loops from St. Boniface showed that the predominant magnetic component comprised superparamagnetic grains, derived from the ash. On both sites, this ash was either dumped as part of midden material from the sites or incorporated into soil horizons, a deliberate amendment strategy also demonstrated through mineral magnetism at Tofts Ness, Orkney (Dockrill and Simpson 1994). Magnetic susceptibility, in conjunction with other archaeological and environmental techniques, was also used to investigate site formation processes with specific reference to house activity areas at Dun Vulan, South Uist (Parker Pearson *et al.* 1996; Marshall and Smith 1999; Giles *et al.* 1999) and Kilphedir, South Uist (Smith *et al.* 2001).

Past mineral magnetic research has therefore demonstrated the strong correlation between magnetic enhancement and the presence of ash within archaeological contexts. This correlation has been confirmed on a number of sites in Atlantic Scotland through soil micromorphology, identification dependent largely on mineral ash and carbonised fuel components within the thin section rather than the fabric or microstructure (Carter 1998a). For example, occupation layers at Scalloway, Shetland (Carter 1998b), St. Boniface, Orkney (Carter 1999) and Dun Vulan, South Uist (Schwenninger 1999) showed a strong correlation of observed ash in thin section and enhanced magnetic susceptibility. Magnetic enhancement in prehistoric soil systems in the Northern Isles has also been attributed to ash input as part of deliberate human amendment strategies (*cf.* Dockrill and Simpson 1994; Batt and Dockrill 1998).

Preliminary mineral magnetic analysis of on-site archaeological sediment from the late Iron Age settlement at Loch na Beirgh in Lewis (Church 1996) showed marked magnetic enhancement of certain generic context types such as hearth material, ash spreads and middens (block of samples denoted LB in Fig. 2). It was also noted that the samples with marked magnetic enhancement contained higher concentrations of carbonised plant macrofossils, establishing the link between the spread of ash and plant material across the site. Mineral magnetism was therefore seen as an invaluable tool for disentangling the complex taphonomy and formation processes of the archaeobotanical assemblages from the nine sites. A preliminary level of analysis was designed, involving the measurement of the magnetic susceptibility of all the samples from a further eight later prehistoric and Norse sites across West Lewis. The basic mineral magnetic data was first used to answer a number of preliminary research questions including;

1) Was the magnetic enhancement observed at Loch na Beirgh repeated at the other sites?
2) Was this magnetic enhancement largely the product of the spread of ash from hearths?
3) Was the link between magnetic enhancement, ash content and carbonised plant macrofossil concentration repeated across the sites?

The results were then used to test the generic taphonomic model outlined above. More detailed research involving the sourcing of the fuel from ash rich material from the nine sites is described elsewhere (Peters *et al.*, this volume; Church *et al.*, submitted).

THE ARCHAEOLOGICAL SITES

All the excavations were undertaken using the University of Edinburgh's Archaeological Research Centre at Calanais Farm as a central base (see Fig. 1). From this centre, an extensive programme of survey and excavation throughout Lewis has run for the greater part of the last 15 years (the Calanais Archaeological Research Project; Harding 2000). The first three sites excavated under this project are found on the Bhaltos Peninsula on the west coast of Lewis. At the time of excavation the sites were of particular interest because they were seen to represent the main Iron Age settlement forms common in the Western Isles. Hence the 'island dun' at Dun Bharabhat, a 'broch' at Loch na Beirgh, and the wheelhouse and cellular complex at Traigh Cnip (Harding and Armit 1990). All three structures are believed to be essentially domestic in function.

Dun Bharabhat (denoted DB) is located in a small loch within the hilly interior of the peninsula. The excavations concentrated on the roundhouse and an adjacent structure that had slumped into the loch and therefore required underwater excavation. The structural sequence begins with ephemeral early Iron Age activity underlying the construction of the complex Atlantic roundhouse. This, in turn, was modified to form a simple cellular unit, which used the interior of the roundhouse and also a remodelled gallery. Radiocarbon dating indicates that the roundhouse was occupied within the

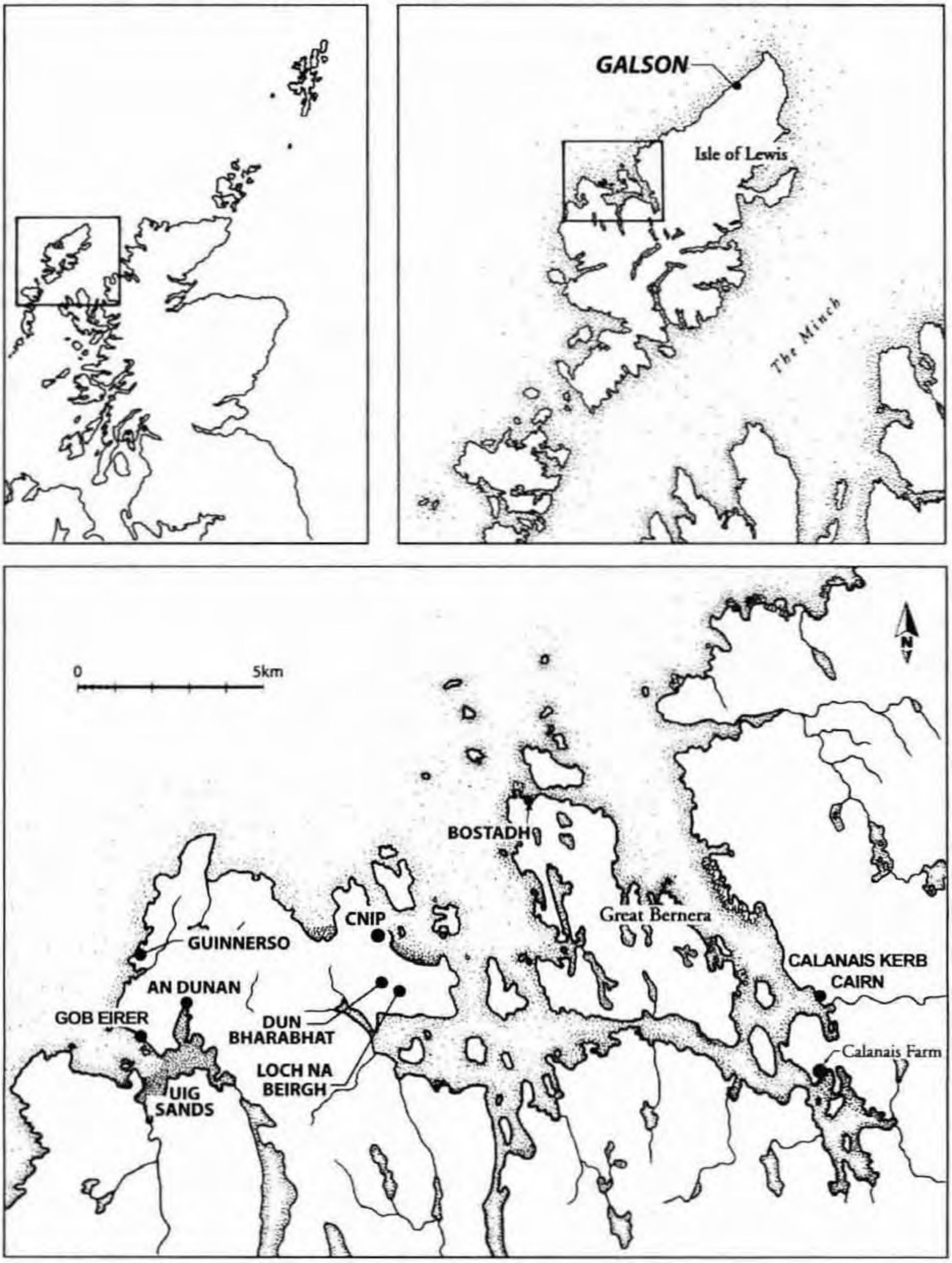

Fig. 1. Location of archaeological sites sampled.

second half of the first millennium BC, with secondary occupation dating from the 1st century cal BC (Harding and Dixon 2000). The wheelhouse and cellular complex at Traigh Cnip (denoted CN) was also multi-phase. The structural sequence started with two adjoining wheelhouses, one incomplete, which had been subsequently modified to create a sequence of cellular buildings followed by a substantial rectilinear structure. Extensive radiocarbon dating suggests the entire sequence was relatively short lived from the 2nd century cal BC to the 2nd century cal AD (Armit 1996). The broch at Loch na Beirgh (denoted LB) is situated at the back of Traigh na Beirgh in a loch that has progressively silted up with windblown sand and organic deposits. During the Iron

Age, this accumulation raised the level of the loch and resulted in successive superimposed phases of occupation within the structure, in an attempt to maintain dry foundations. A sequence of deposits of over 2.5 m has already been uncovered, with the primary levels of occupation of the secondary roundhouse and complex Atlantic roundhouse still to be excavated. The known structural sequence starts with the complex Atlantic roundhouse, followed by the construction of a substantial secondary roundhouse within the structure's interior, the upper levels dated by radiocarbon to the 2nd to 4th centuries cal AD. There then appears a complex sequence of smaller cellular units, radiocarbon dated to the 3rd to 6th centuries cal AD. These are replaced in due course by 'figure-of-eight' buildings dating to the second half of the first millennium AD from artefact association (Harding and Gilmour 2000).

The fourth site excavated was a kerb cairn (denoted CC), excavated in advance of road widening near Calanais (Neighbour 1997). Three principal sets of features were recovered; Neolithic pits and hollows overlain by an old ground surface that was in turn severely truncated by the foundation pit dug for the kerb cairn. The main body of the cairn comprised of interleaved layers of ash and decomposed organic material that respected a central cist containing a broken urn associated with the cremated remains of one, or maybe two, individuals. Radiocarbon dating of cereal grain places the accumulation of the ash spreads between 1800–1500 cal BC.

The Uig Peninsula is adjacent to the Bhaltos Peninsula and was the focus of a programme of survey and excavation between 1995 and 1998. Three sites were excavated following a detailed walkover survey: Gob Eirer, An Dunan and Guinnerso. Gob Eirer (denoted GE) is a promontory fort situated on a small stack overlooking Camas Uig (Church *et al.* 1999). Excavations revealed a thick drystone wall on the landward side of a stack with a small entrance in the centre of the wall. A cobbled path lead from the entrance into the centre of the enclosed area to a partially excavated oval domestic structure, radiocarbon dated to the first half of the first millennium BC (Bronk Ramsey *et al.* 2000). The site was provisionally interpreted as being domestic. An Dunan (denoted AD) is an islet site located in a small area of saltings leading from Camas Uig. The main phase of the site consists of an elaborate central hearth with multiple ash levels *in situ*, some of which contained human bone. Large amounts of ash had spread from the hearth to form mixed floor levels contained within a d-shaped structure, with rubble walls reminiscent of burial cairn construction. Multiple radiocarbon dates indicate use from 3rd to the 1st century cal BC (Bronk Ramsey *et al.* 2000). Initial interpretation of this structure highlights its specific role as a ceremonial site for human cremation, unique within the Atlantic Scottish Iron Age (Burgess *et al.* 1998). The multi-phase sequence of structures at Guinnerso (denoted GUN) is situated within the extensive moorland of the Uig Peninsula. Two main phases have been identified; a cellular complex of probable mid Iron Age date from the pottery assemblage and a later Medieval phase, with occupation of the main small double entranced structure radiocarbon dated to 15th to 17th century cal AD (Bronk Ramsey *et al.* 2000). This paper uses data from the mid Iron Age phase only. Post-excavation analysis is still ongoing, however initial interpretation of the site suggests seasonal occupation, for specific economic and industrial activities such as transhumance and pottery manufacture (Church and Gilmour 1999).

The additional two sites from Lewis were revealed by coastal erosion of machair at Bostadh, Great Bernera and Galson on the northwest coast. Bostadh (denoted BO) consisted of three well preserved late Iron Age 'figure-of-eight' houses overlain by an extensive midden and a small fragment of a rectilinear structure of Norse date (Neighbour and Burgess 1997). At Galson (denoted GAL), past research has revealed two major levels in the eroding section; a number of Iron Age burial cists (Neighbour *et al.* 2001), overlain by domestic dwellings of Iron Age to Medieval date towards the top of the eroding section (Neighbour and Church 2001). The principal archaeological features consisted of two separate house complexes of late Iron Age / Norse date in the upper level with associated hearths, ash spreads, middens and palaeosols (Peters *et al.* 2000).

SAMPLING AND LABORATORY METHODOLOGY

The authors' involvement with the on-site sampling only started from 1995. The three sites from the first research project in Bhaltos (Dun Bharabhat, Cnip and the late Iron Age structures at Loch na Beirgh) were therefore only sampled when the excavator deemed a context worthy of sampling, usually due to perceived ecofactual richness or archaeological importance of the deposit. This strategy is known as *judgement* sampling (Jones 1991). All of the sites excavated from 1995 onwards implemented a strategy of either *random* or *total* sampling of well-defined, sealed and undisturbed contexts (Jones 1991), with the *random* samples chosen at Loch na Beirgh using random number tables (van der Veen and Feiller 1982). Two samples were taken from each deposit; a bulk sample of between 14–28 litres for wet sieving and a routine sample of approximately 0.25 litres, for basic soil tests including mineral magnetic analysis. Close interval (2 cm.) mineral magnetic profiles were also taken at Galson (Peters *et al.* 2000) and Guinnerso (Peters *et al.* 2001) to investigate the mineral magnetic character of the occupation layers in more detail.

The bulk samples were processed using a flotation tank (Kenward *et al.* 1980) with the residue held by a 1.0 mm net and the flot caught by 1.0 and 0.3 mm sieves respectively. All the flots and residues were air-dried and the flots sorted in their entirety. All material greater than 4 mm was also sorted from the residues (including charcoal), with the smaller residue fractions (2 mm and 1 mm) from a random number (10%) of the samples also chosen from each site to test for flot recovery rates. Over 80% of the total plant macrofossils were recovered from the flot at all of the sites, with some sites, especially those in the machair with recovery rates of over 90%. Also, heavier classes of plant material, such as hazel nut that have been shown to remain in the residue in certain soil types (*cf.* van der Veen 1983), were present in the flot and so no further sorting of the residues was undertaken. A single parameter was used in this analysis for gauging carbonised plant macrofossil concentration. This parameter was standardised by dividing the total number of quantifiable components (QC) by the number of litres of the original bulk sample, resulting in QC/litre for each sample.

Magnetic susceptibility measures the 'magnetizability' of a material (Dearing 1994), through placing the sample in a small alternating magnetic field and measuring the response. Samples were prepared for laboratory measurement by first describing their texture and colour using a Munsell colour chart (1992). The samples were then dried for 24 hours at 40°C, to remove the diamagnetic component of the water, and sieved through a 2mm gauge, to remove large archaeological and natural clasts. Volumetric magnetic susceptibilities (κ_{lf} and κ_{hf}) were then measured at low and high frequencies using a Bartington MS2 susceptibility bridge, and the soil weighed. This allowed the two basic parameters of mass specific magnetic susceptibility (χ) and frequency dependent susceptibility (κ_{fd}) to be calculated, following Dearing (1994). Normalising χ by the mass removes the variability in sediment compaction and allows direct comparison of the concentration of magnetic grains between samples. κ_{fd} provides an estimation of the concentration of superparamagnetic grains (see Peters *et al.*, this volume for discussion on domain state).

Every sample was assigned to a generic context type from site observation by the authors and reference to the site record (see Table 1 for the different classifications). Clearly, this involved the simplification of the extremely complex phenomenon of site formation process. For example, the formation processes of 'floor levels' have generated much research and discussion in Atlantic Scotland (*cf.* Matthews 1993; Carter 1999; Schwenninger 1999; Smith *et al.* 2001; Milek 2001). However, this classification allowed samples of specific generic context types with similar ranges of taphonomic complexity to be grouped prior to analysis. For example, the archaeobotanical material within a coherent ash spread is likely to have been carbonised during the creation of that ash whilst an archaeobotanical assemblage within a floor level was formed from an unknown number of discard events (*cf.* Dennell 1974; 1976). The classification also highlighted samples from context types, such as wall fills, that may have been formed from material redeposited from different periods.

RESULTS

Table 2 shows the number of samples analysed and the breakdown of generic context types for each site. The breakdown reflects the stratigraphic and functional character of the site, with greater variety generally displayed by the sites with a predominantly domestic function. For example, the three structural complexes within the machair (Cnip, Galson and Bostadh) have a wide variety of context types such as hearth material, ash spreads, floor levels and middens. Conversely, Calanais kerb cairn only has three context types (ash spread, negative feature fill and old ground surface) reflecting the three principal sets of features on this funerary site. The results are discussed with reference to the three research questions outlined in the introduction above.

Was the magnetic enhancement observed at Loch na Beirgh repeated at the other sites?

Fig. 2 presents the χ readings from all the samples, from the lowest to the highest values in order, from each site. Table 3 shows a selection of values for the surrounding 'natural' soil matrix for each of the sites. In general, it can be seen that the magnetic enhancement observed at Loch na Beirgh is repeated at all of the sites, except for Gob Eirer. However, a wide variability is observed between the general profiles of each site that is dependent largely on the site formation processes and the breakdown of the generic context types that make up the site. For example, most of the contexts sampled from An Dunan have marked magnetic enhancement, where as over half of the samples from Bostadh have relatively low magnetic concentration, a disparity that can be explained by the generic context types sampled from the two sites. An Dunan consisted of mostly hearth material, ash spreads, floor levels, occupation levels and cell fills with a significant ash component where as the Bostadh samples with low χ values consisted of various contexts types, such as cell and wall fills, which were almost 100% machair sand. The one site where magnetic enhancement was not seen was Gob Eirer, with only one sample from an occupation level with significant magnetic concentration. Post-depositional processes that altered the magnetic properties of the soil, principally localised waterlogging, appears to have lead to the dissolution of the mineral grains and their removal by leaching. Subsequent re-deposition in the form of extensive iron pan deposits was observed across the site. In view of this, the magnetic data from Gob Eirer has not been used in further analysis.

Table 1. Generic context type classifications used for samples.

Generic context type	Description	Abbreviation
Ash spread	Ash rich context within occupation levels.	AS
Cell/feature fill	Mixed material filling a structural cell or feature.	CFF
Clay (natural)	Natural clay within site, presumably as material for pot manufacture.	CL
Floor level	Distinct occupation level that appears during excavation to be contemporary with main structural features.	FL
Foundation deposit	Mixed layer that appears to be deliberately laid down as a foundation for structural features.	FD
Hearth material	Ash or burnt material found within, or immediately adjacent to an in situ hearth.	HM
Midden	Mixed material, rich in 'domestic' debris, that appears during excavation to be contemporary with main structural features.	M
Negative feature fill	Negative feature fill (pit fill, ditch fill, post-hole) sealed by phased material.	NFF
Occupation level	Generic context with admixture of archaeological material that appears during excavation to be contemporary with main structural features.	OL
Old ground surface	Relic soil horizon.	OGS
Subsoil	Subsoil or parent material	SS
Rubble	Stone rich deposit containing clear evidence of collapsed structural features.	R
Topsoil or post-deposition soil formation	Topsoil or post-deposition soil formation	TS
Wall fill	Mixed material used to fill or support wall material.	WF
Wind blown sand	'Natural' sand levels.	WBS

Table 2. Sample total and generic context type breakdown for each site.

Site	χ analysis	K_{fd} analysis	AS	CFF	CL	FD	FL	HM	M	NFF	OGS	OL	R	SS	TS	WBS	WF
AD	126	126	21	38	7	1	6	20		9		1		1	6		16
BO	222	11*	8	53			15	8	37	24	2	22	3			19	31
CC	49	49	10							32	7						
CN	37	37	5	10	1	2	8	1	2	2		4				1	1
DB	19	19		2	2			5		1		8					1
GAL	24	24	4	1			6	1	7		1					4	
GE	49	49	3				5			5		19	2	4	7		4
GUN	24	24	6				11	5				2					
LB	55	55		20		3	3	7	6	6	4		3				3
Totals	**605**	**394**	**57**	**124**	**10**	**6**	**54**	**47**	**52**	**79**	**14**	**56**	**8**	**5**	**13**	**24**	**56**

* χ only measured for majority of samples from Bostadh.

Was this magnetic enhancement largely the product of the spread of ash from hearths?

To answer this question, we need to first demonstrate magnetic enhancement in samples from hearth material and associated ash spreads. Fig. 3 presents the samples from all the sites (except for Gob Eirer) grouped by context type and arranged in order of increasing χ. Samples from hearth material and ash spreads are seen to undergo significant enhancement. More variable values are recorded for cell fills, floor levels, middens, negative feature fills, occupation levels and wall fills. It is proposed that this variability is related to the proportion of ash within the deposit. For example, the negative features underlying the old ground surface at Calanais kerb cairn have relatively low χ values (Fig. 4) with little ash content from the excavation records. Conversely, the negative features within Loch na Beirgh contained variable proportions of ash on excavation, which is demonstrated in the laboratory by the more variable χ values (Table 3). The context types with generally low χ values (e.g. old ground surfaces and wind blown sand) by their very nature have relatively little ash in their composition. However, slight magnetic enhancement in these latter context types has been used to demonstrate soil amendment strategies elsewhere in Atlantic Scotland (*cf.* Dockrill and Simpson 1994; Batt and Dockrill 1998).

Table 3. Selected data of 'natural' soil matrix from most sites.

Site	Generic context	χ ($10^{-6}m^3kg^{-1}$)	κ_{fd} (%)	QC/litre
AD	SS	0.28	3.57	0.0
LB	OGS	0.25	4.76	1.1
LB	OGS	0.11	0.00	0.8
LB	OGS	0.33	5.13	3.7
LB	NFF	0.39	2.5	1.9
LB	NFF	0.58	5	1
LB	NFF	1.87	7.42	2
LB	NFF	2.06	8.49	0.5
LB	NFF	2.89	7.43	0.5
LB	NFF	4.17	7.21	18.3
BO	WBS	0.04	n/a	0.0
BO	WBS	0.05	n/a	0.07
BO	WBS	0.07	n/a	0.0
BO	WBS	0.08	n/a	0.07
CC	OGS	0.13	5.88	0.0
CC	OGS	0.28	5.88	0.0
GAL	Raised beach	1.06	2.78	0.0
GAL	WBS	0.60	4.67	0.0
GAL	WBS	0.36	4.38	0.0
GAL	WBS	0.16	4.66	0.0
GAL	WBS	0.34	4.86	0.0
GE	SS	0.11	12.5	0.0
GE	SS	0.02	0.00	0.0
GE	SS	0.10	6.25	0.1
GE	SS	0.03	0.00	0.0

Close-interval (2 cm) sampling through an eroding Norse structure at Galson (Peters *et al.* 2000) also demonstrated the magnetic enhancement from the central hearth into the surrounding floor level (Fig. 1a in Peters *et al.*, this volume). This enhancement within the floor level related to the spread of ash from the hearth, identified through on-site observation and soil micromorphology (Tams 2003). The identification of ash within the thin sections of the floor was based on observed concentrations of mineral ash and carbonised amorphous material, interpreted as burnt peat. None of this material was observed within the underlying windblown sand that recorded trace levels of magnetic enhancement. Using the same techniques of close-interval mineral magnetic sampling and soil micromorphology, the correlation between ash and magnetic enhancement was examined from four localities: an earlier Norse midden at Galson (Fig. 1b in Peters *et al.*, this volume), much of the stratigraphy from An Dunan, and the occupation horizons from Bostadh and Guinnerso (Tams 2003; Peters *et al.* 2001). Fig. 4 also shows the magnetic enhancement from the ash spreads at Calanais kerb cairn, compared to the earlier negative features and old ground surface. Again, thin sections were prepared for soil micromorphology through a section of this burnt material, including the underlying soil horizons (Carter 2001). The burnt levels were almost entirely composed of the oxidised or reduced residues of burnt fuel that were characterised by very high reflectance in oblique incident light due to the heating of iron oxides present in the fuel (Courty *et al.* 1989). Carbonised fragments of the fuel were also identified. The old ground surface and mineral subsoil below had little evidence of ashy material and significant mineral magnetic enhancement was not observed.

We can therefore assume that the magnetic enhancement in most context types stems from the spread of ash from hearths or other burning activities that are usually recovered during the excavation. Further information on the domain state (see Peters *et al.* this volume) of the magnetic material can be gained from plotting χ against κ_{fd} for each of the samples with κ_{lf} values of 100 or greater. The cut off point was chosen as material with a weak magnetic signal ($\kappa_{lf} < 100$) is more likely to give incorrect κ_{fd} values (Dearing 1994). Fig. 5 presents 221 samples from all of the sites plotted in this way. Most of the samples plot between 6 and 10% for κ_{fd}, meaning a sizeable proportion of the magnetic grains is made up of superparamagnetic grains, a consistent magnetic signal most likely explained by the ash being produced from a similar burning process and/or fuel source.

Was the link between magnetic enhancement, ash content and carbonised plant macrofossil concentration repeated across the sites?

To test this hypothesis, the relationship of magnetic concentration (χ) and macrofossil concentration (QC/litre) can be analysed on a site by site basis. Fig. 4 presents data from Calanais kerb cairn as an example. It can be seen that the negative feature fills and old ground surface underlying the cairn have relatively low χ and QC/litre values whereas the ash spreads that comprise a large part of the body of the cairn display significant magnetic enhancement and concomitant increased macrofossil concentration. The increase in macrofossil concentration is not proportionally related to an increase in the magnetic susceptibility. Instead, once a threshold in the increase of magnetic susceptibility is reached, it is possible for significant levels of plant macrofossils to be recovered. In other words, this threshold applies to the quantity of quantifiable components per litre that can only be significantly increased above a certain level of χ. Samples with greater values of χ can also contain significant concentrations of carbonised plant remains but there is no linear correlation with archaeobotanical concentration and the increase in χ.

This threshold concept can be tested by grouping samples from all of the sites into classes of increasing χ and calculating the mean and median QC/litre for each class (Table 4). The results are plotted for each χ class midpoint in Fig. 6. Again, this shows that there are low QC/litre values for the weaker χ classes up to 0.5 $10^{-6}m^3kg^{-1}$, the threshold beyond which significant macrofossil concentration can be observed. A difference in magnitude can be seen between the mean and median QC/litre for each class, highlighting the variation in

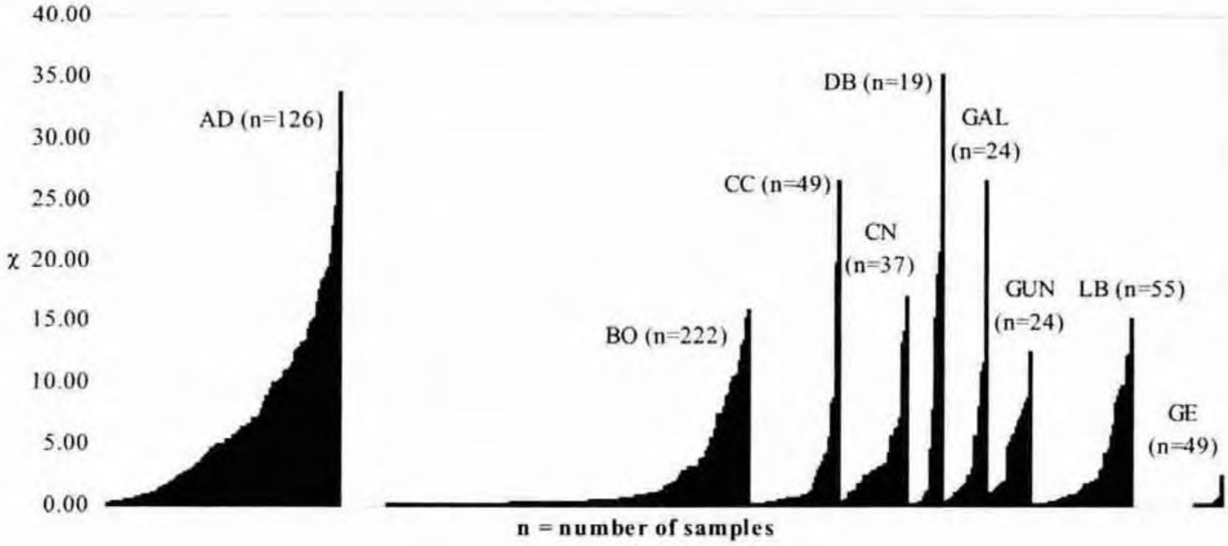

Fig. 2. χ (units = $10^{-6}m^3kg^{-1}$) from all sites.

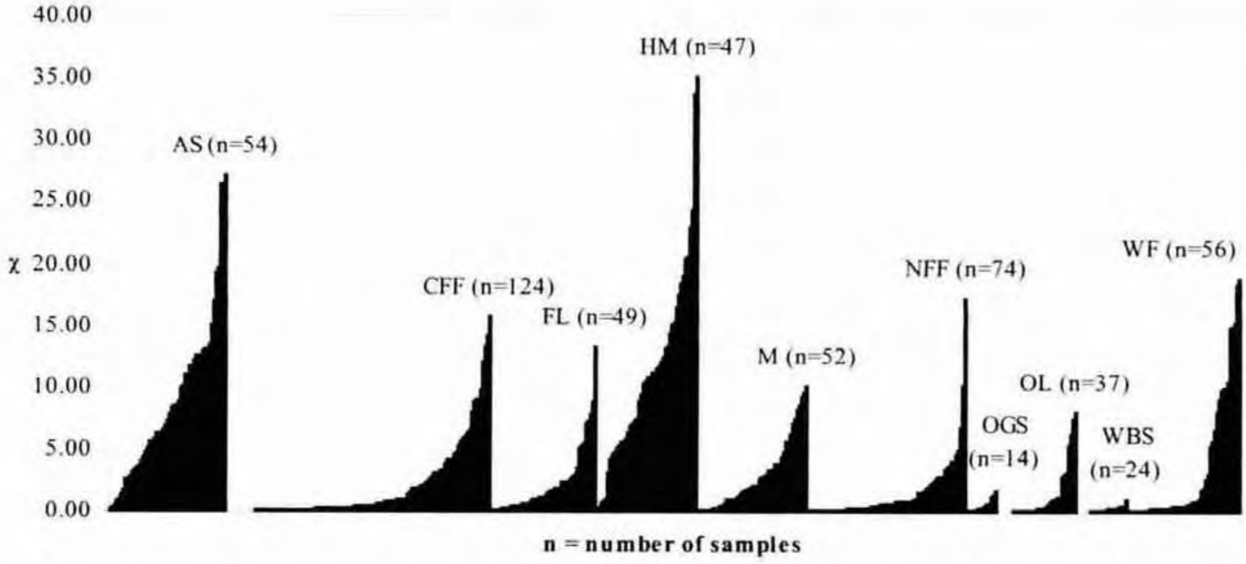

Fig. 3. χ (units = $10^{-6}m^3kg^{-1}$) by main context types from all sites (except Gob Eirer).

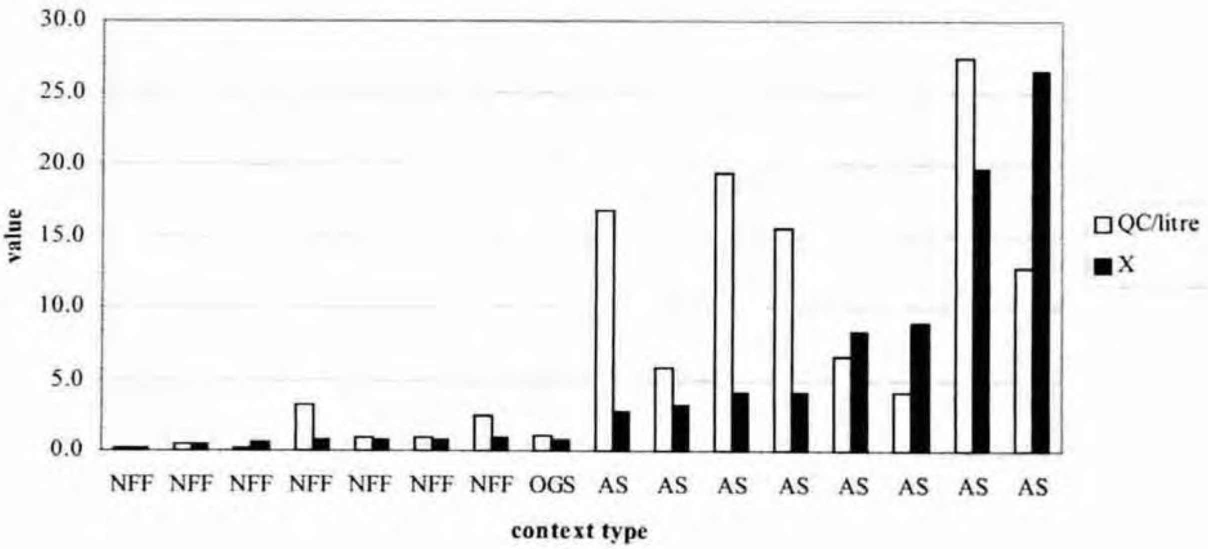

Fig. 4. χ (units = $10^{-6}m^3kg^{-1}$) and QC/litre for Calanais kerb cairn.

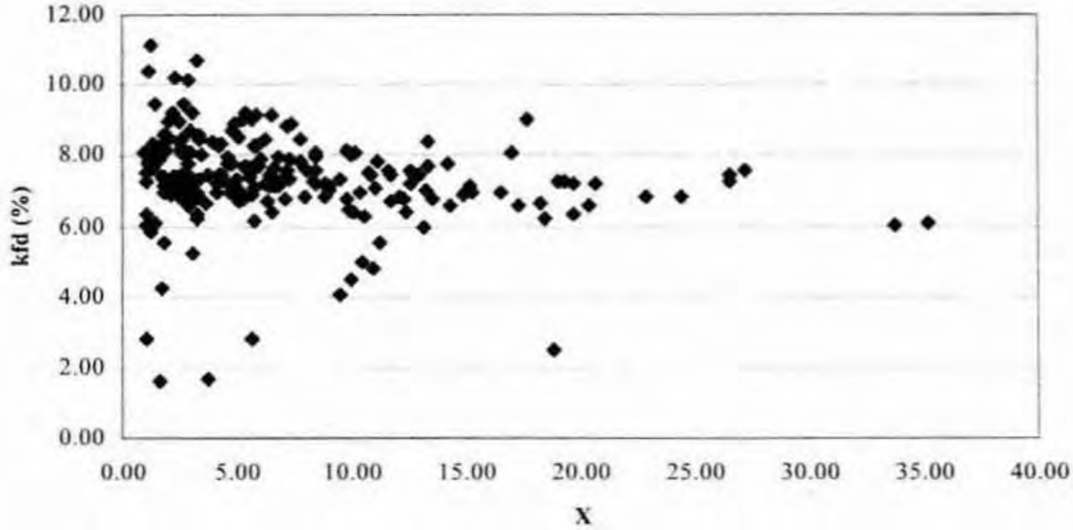

Fig. 5. χ (units = $10^{-6}m^3kg^{-1}$) by κ_{fd} for all samples with κ_{lf} > 100.

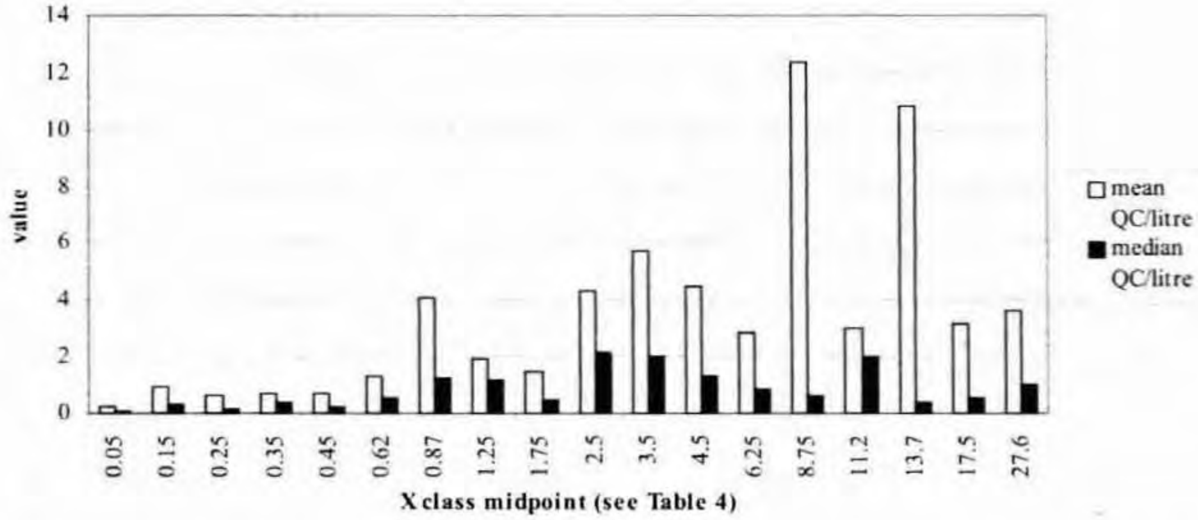

Fig. 6. χ class midpoints (units = $10^{-6}m^3kg^{-1}$) and QC/litre for all sites (based on data from Table 4).

macrofossil concentration for each class with both low and high QC/litre values possible beyond this threshold. However, very few samples with significant macrofossil concentration have weak magnetic signals. Therefore, in general it can be proposed that significant carbonised plant macrofossil concentration within an archaeological deposit within the study area correlates to a significant magnetic enhancement stemming from the input of ash into the context. This input of ash into sediment can therefore be proposed as the primary taphonomic pathway for archaeobotanical material into that deposit.

DISCUSSION

Several *in situ* hearths were recovered from each of the domestic sites and the associated hearth material and adjacent ash spreads displayed marked magnetic enhancement with variable carbonised macrofossil concentrations. The subsequent spread of this ash, through various human, accidental or natural processes, can also be demonstrated through magnetic enhancement of associated archaeological deposits. In this way, a large proportion of the macrofossils recovered from an archaeological phase would have ultimately been carbonised in the hearth(s) within the structure. These hearths act as the most common position for carbonising plant material on the sites through incorporating the plants into the fire and ash. It is uncertain whether this was deliberate as kindling or fuel, or happened accidentally through an unknown number of variable human and natural processes. The two funerary sites investigated also showed the correlation of magnetic enhancement, ash input and macrofossil concentration. However, it is likely that the ash would have been produced through potentially different burning episodes and processes than those

Table 4. QC/litre grouped according to χ value for all sites (except Gob Eirer).

χ range ($\mu m^3 kg^{-1}$)	class midpoint	average QC/l	median QC/l	lowest QC/l	highest QC/l	number of samples
0 – 0.09	0.045	0.23	0.07	0	4	26
0.1 – 0.19	0.145	0.93	0.29	0	12.2	52
0.2 – 0.29	0.245	0.63	0.18	0	7	46
0.3 – 0.39	0.345	0.69	0.4	0	3.71	35
0.4 – 0.49	0.445	0.72	0.21	0	9.09	20
0.5 – 0.74	0.62	1.34	0.57	0	13	30
0.75 – 0.99	0.87	4.09	1.21	0	32.07	26
1.00 – 1.49	1.245	1.92	1.17	0	10	32
1.5 – 1.99	1.745	1.48	0.43	0	10.07	29
2.00 – 2.99	2.495	4.35	2.18	0.21	25	14
3.00 – 3.99	3.495	5.76	2	0	57.07	22
4.00 – 4.99	4.495	4.46	1.33	0	19.44	16
5.00 – 7.49	6.245	2.85	0.82	0	24.79	47
7.5 – 9.99	8.745	12.38	0.61	0	270.29	27
10.00 – 12.49	11.245	2.99	2.04	0	12	17
12.5 – 14.99	13.745	10.83	0.36	0	112.64	14
15.00 – 19.99	17.495	3.18	0.56	0	27.4	13
20.00 – 35.15	27.575	3.64	1	0	15.5	9

occurring in a domestic hearth. The consistently high proportion of superparamagnetic grains within the domain state profile of most of the samples strengthens the impression of a similarity of burning process producing the ash. Experimental archaeology with replica hearths and various fuel types has suggested that this consistent signal is likely to relate to the type of fuel used (Peters *et al.*, this volume). Subsequent detailed analysis of ash spreads from all the sites has also suggested that the main fuel type used was well-humified peat (Church *et al.*, submitted). This would have been available from the large tracts of blanket bog that would have covered much of the interior of Lewis by the first millennium BC.

The research described here has demonstrated the application of mineral magnetism as an independent proxy to test the validity of the taphonomic model outlined above. However, caution must be exercised in interpreting the taphonomic history of archaeobotanical assemblages in Atlantic Scotland from this model alone as specific sets of archaeological deposits have yielded large quantities of carbonised plant material not derived from the ash spread from hearths. For example, large quantities of barley ears and straw were discovered on the floor of a secondary phase in Broch 2 at the Howe in Orkney (Ballin-Smith 1994) that appears to have resulted from a crop-processing accident (Dickson 1994). Also, a number of conflagration deposits have yielded very well preserved carbonised plant macrofossils that represent a different taphonomy to the majority of deposits excavated in the region (*cf.* Church 2000).

One of the key implications from this generic model is the preservation system for carbonised plant macrofossils within the ash of a typical domestic hearth. Detailed mineral magnetic measurements have been taken from the replica domestic hearths mentioned above (Peters *et al.* 2001). Based on high temperature susceptibility measurements, approximate thermal histories of the peat ash were estimated with most of the material heated to over 700°C. Boardman and Jones (1990) demonstrated that most plant material would be totally destroyed or severely degraded at this temperature. They showed that cereal chaff, including culm internodes and various parts of the ear of both glume and free-threshing cereals, were much more susceptible to destruction by burning than hardier elements, such as the grain itself. Wilson (1984) also demonstrated that seeds were easily destroyed and that variability in the rate and extent of destruction occurred between different species, dependent on temperature, atmospheric conditions, moisture content and seed structure.

The poor preservation conditions within domestic hearths burning peat is reflected by the generally very poor preservation that characterises the archaeobotanical assemblages recovered from the seven domestic sites in West Lewis. For example, Fig. 7 presents the preservation profile of cereal caryopses recovered from most of the sites, following the preservation indices outlined by Hubbard and al Azm (1990), with class P1 representing perfectly preserved grain to class P6 representing severely degraded grain precluding even genus identification. Generally over 50% of the grain from most of the assemblages lay within the two worst preservation classes, indicating severe degradation of the grain during the carbonisation process. Less robust classes of material including chaff and wild seeds would be easily destroyed within this sort of carbonisation (Boardman and Jones 1990). Conversely, the grain from a barley thatch within a conflagration within the secondary structure in Dun Bharabhat (C.169) recorded over 65% of the grain within the two best preservation classes (Church 2000). This

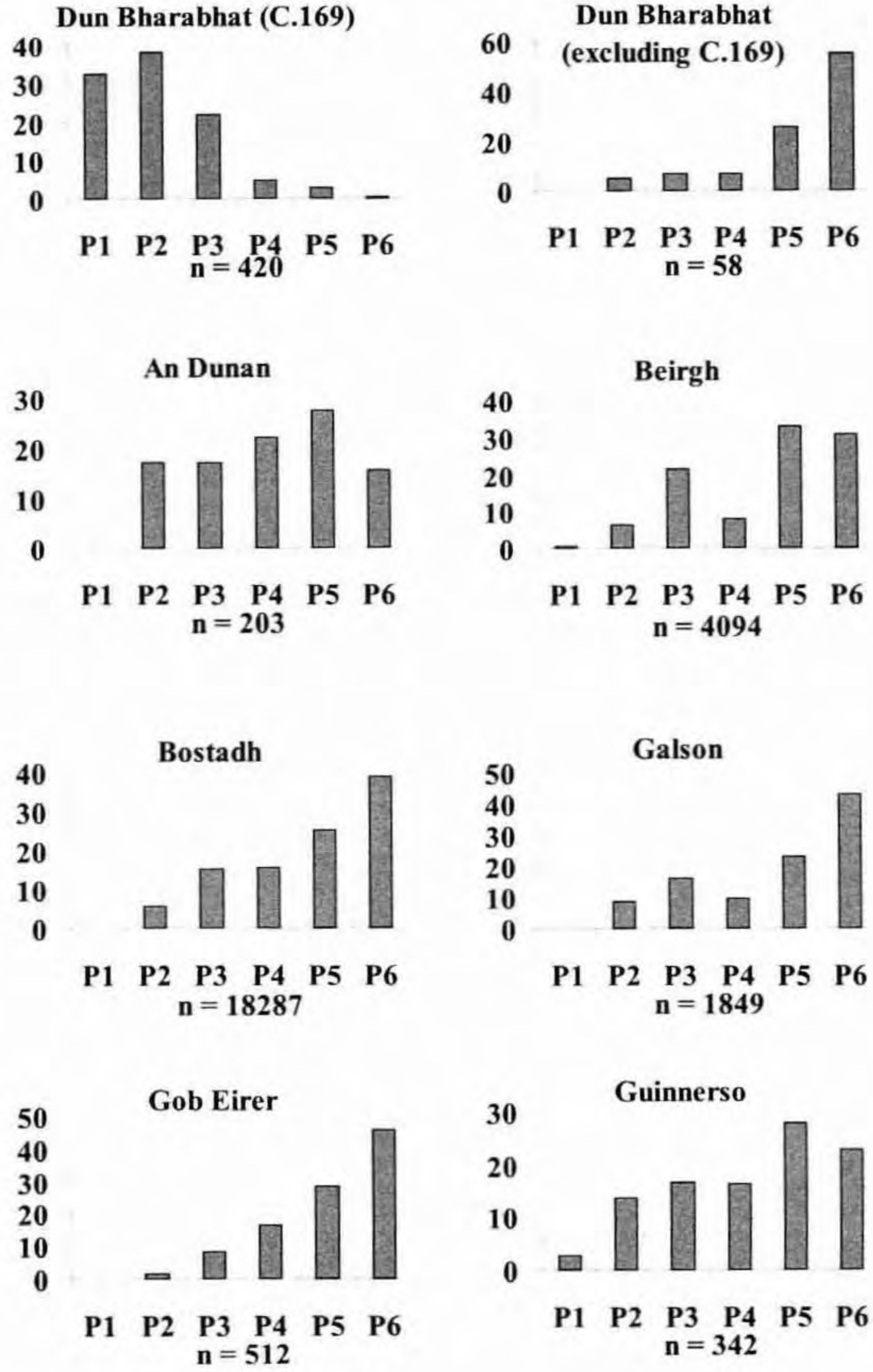

Fig. 7. Grain preservation of selected sites in West Lewis (x axis = preservation index after Hubbard and al Azm (1990); y axis = percentage of total assemblage).

indicates near perfect preservation, stemming from the slow carbonisation of the plant material in a relatively low temperature, reducing atmosphere within the collapsed structure. The effects on the preservation of the archaeobotanical assemblages from the differing taphonomic histories are clear. Most of the archaeobotanical assemblages from the West Lewis study area stem from domestic hearths and therefore contain significant proportions of degraded cereal grain and other hardy plant parts, such as culm bases and rhizomes (*cf.* Church 2000).

CONCLUSIONS

1. In general, magnetic enhancement was observed throughout a range of archaeological deposits on each of the sites sampled (except for Gob Eirer as a result of post-depositional pedological processes).
2. It is proposed that this magnetic enhancement in most types of context stem from the spread of ash from hearths or other burning activities.
3. The results indicate that there is a clear linkage between magnetic enhancement, ash content and carbonised plant macrofossil concentration across the sites. A critical threshold in magnetic susceptibility, an approximate indication of ash content, is highlighted beyond which significant concentrations of plant macrofossils can be recovered.
4. A general model of archaeobotanical taphonomy is confirmed, involving the carbonisation of much of the plant material in hearths and the subsequent spread of ash, by various routes, creating the archaeobotanical assemblages recovered.
5. A key implication is the very poor preservation environment for the carbonisation of plant macrofossils in fires with peat as its main fuel.

Acknowledgements
Dr. Geraint Coles is thanked for commenting on an earlier draft. Dr. Ian Armit is thanked for permission to use and amend Fig. 1, illustrated by Kevin Hicks. We would also like to thank the directors of the various excavations including Professor Dennis Harding, Dr. Simon Gilmour, Dr. Ian Armit and Tim Neighbour for access to the Lewis material. Dr. Steve Carter and Adrian Tams are thanked for access to unpublished reports. The work was supported by a Caledonian Research Foundation Scholarship and a Leverhulme Fellowship to M. J. Church and a British Petroleum / Royal Society of Edinburgh Research Fellowship to C. Peters.

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